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RARIE: A RELATIVE RANGING SYSTEM FOR RESEARCH SHIPS.(U)
AUG 61 J A GILBREATH, J R VAUGHAN

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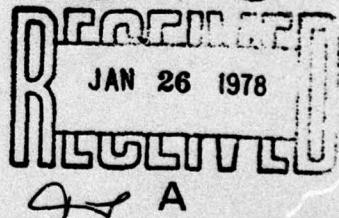
J. A. Gilbreath, J. R. Vaughan, R. B. Wheeler

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RESEARCH AND DEVELOPMENT REPORT
REPORT 1066
30 AUGUST 1961

NEL/Report 1066

THE PROBLEM

Develop a method for positioning one surfaced submarine, or surface ship, relative to another one at ranges up to 100 miles, or more, with an accuracy of 0.1 mile. More specifically, provide a means of measuring the separation between two vessels engaged in underwater sound propagation studies for the Lorad program.

RESULTS

1. Two developmental ranging (RARIE) equipments were constructed and evaluated at sea.
2. The equipments were used to measure the separation between two surfaced submarines at all ranges up to 60 miles. It is probable that ranges considerably greater than 100 miles can be measured.
3. The accuracy was ± 0.1 mile.
4. In addition to supplying range information, RARIE provided the scientific parties with voice communications that did not interfere with regular ship communications.

RECOMMENDATIONS

1. Redesign the equipment with simplification and miniaturization of the various components as the primary objective.
2. Consider procurement of the equipment by other Naval activities as a means of expediting submarine and surface ship positioning at ranges greater than radar range.

ADMINISTRATIVE INFORMATION

Work was conducted under AS 02101, S-F001 03 02, Task 8016 (NEL E1-3), the Lorad problem. The project was initiated in December 1958 on a low priority basis, and the equipment was completed in June 1960. The report was approved for publication 30 August 1961.

The development of RARIE was made possible by the cooperation of many people. In particular, J. L. Whitaker of the Radar Design Section, M. L. Tibbals of the Navigational Systems Section, the Marine Services Section, and the other members of the Communication and IFF Section made valuable contributions.

CONTENTS

<u>Page</u>	
4	INTRODUCTION
4	GENERAL DESCRIPTION OF SYSTEM
8	FUNCTIONAL DESCRIPTION
8	General
10	Synchronizer/Indicator Unit
14	Transmitter
15	Control/Monitor Unit
19	SEA EVALUATION
20	CONCLUSIONS
20	RECOMMENDATIONS
21	APPENDIX: OPERATING PROCEDURE
22	REFERENCES

ILLUSTRATIONS

<u>Page</u>	<u>Figure</u>	
6-7	1	Photographs of RARIE equipment
9	2	RARIE block diagram
11	3	Master station display
12	4	Master and slave station displays
16	5	Block diagram of transmitter unit
18	6	Schematic of sync circuits

TABLE

<u>Page</u>	<u>Table</u>	
14	1	Frequency Allocation Chart

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INTRODUCTION

A problem inherent in sea tests of the Lorad system has been the accurate positioning of the target submarine at a specific range relative to the echo-ranging vessel. The classical method for accomplishing this positioning was to commence from a rendezvous point and open range on reciprocal bearings. One submarine would track the other by radar out to the limit of radar range and thus obtain an opening range rate. Information was radioed to the target vessel when correct separation range had been achieved. This method was unreliable and usually required considerable maneuvering after the vessels submerged, with aid from sonar station-keeping to obtain the desired separation for echo-ranging. After surfacing it was often necessary to repeat the above procedure in order to get on station again. Considerable time which could have been used for the operation was lost because of lengthy repositioning runs.

This problem made it evident that some positive navigational aid was required to station the vessels before submergence. In very-long-range signal propagation studies the chance for error becomes even greater and the difficulties of assuming stations more time consuming. Limited time for sea tests makes it imperative that submarine time be most efficiently employed to perform all the tests required for a system as complex as Lorad.

RARIE (RAdio Range Interrogator Electronic) was developed and constructed at NEL to meet the need for a navigational system for determining the relative range between two vessels on the surface. The system has been used successfully out to a range of 60 miles with an estimated accuracy of ± 0.1 mile. It is expected that ranges of 100 miles and greater can be achieved when the opportunity for such tests occurs.

GENERAL DESCRIPTION OF SYSTEM

RARIE is a dual synchronous system of radio-frequency pulse exchange. The three pieces of equipment involved

(fig. 1) are the receiver, the indicator, and the transmitter. Their combined functions and method of operation are described in the section entitled "Functional Description" (p. 8). The frequencies utilized have good ground-wave propagation characteristics and lie in the navigation band also used by Loran¹ (see list of references at end of report) and other pulse systems.

The principle of operation is the measurement of travel time (in microseconds) of a radio pulse making a round trip between two RARIE-equipped vessels. The frequency of the transmitted radio pulse, 1975 kc/s, was selected for least interference with Loran, EPI,² and other signals in this frequency region. Pulses of 500 watts peak power with a repetition rate of approximately 34 c/s are transmitted by both master and slave station. The slave-station pulses are synchronized so that they are transmitted exactly one-half period after the master station pulses are received. The master station measures the time delay between its transmitted pulse and reception of slave pulses by oscillographic pulse matching, subtracts the known fixed delays, and arrives at a net time delay due to propagation. The measured delay represents the round-trip travel time plus other delays which are not compensated by the receiver, such as those which occur in antenna coupling. This extra delay is referred to as the correction factor. Its value is determined by calibration using ship's radar as a standard. It is usually found to be in the neighborhood of 12 μ sec, depending somewhat on the type of antenna used on the target vessel.

There are three principal functions of each ship-station equipment: (1) to transmit radio frequency pulses to the other ship station; (2) to receive similar pulses from the other station; and (3) to present the envelopes of the transmit and receive signals on the screen of a cathode-ray tube in such a way that when the leading edges of the two pulses are aligned, by means of an adjustable calibrated time delay circuit, the total round-trip time delay can be measured.

A single antenna serves for both transmission and reception of signals. A horizontal line antenna, approximately 100 feet in length, is mounted on the forward deck of each submarine extending from the conning tower to a mast mounted near the bow. The lead-in is attached to the approximate center of the line and passes into the forward torpedo room of the submarine through a special torpedo loading hatch

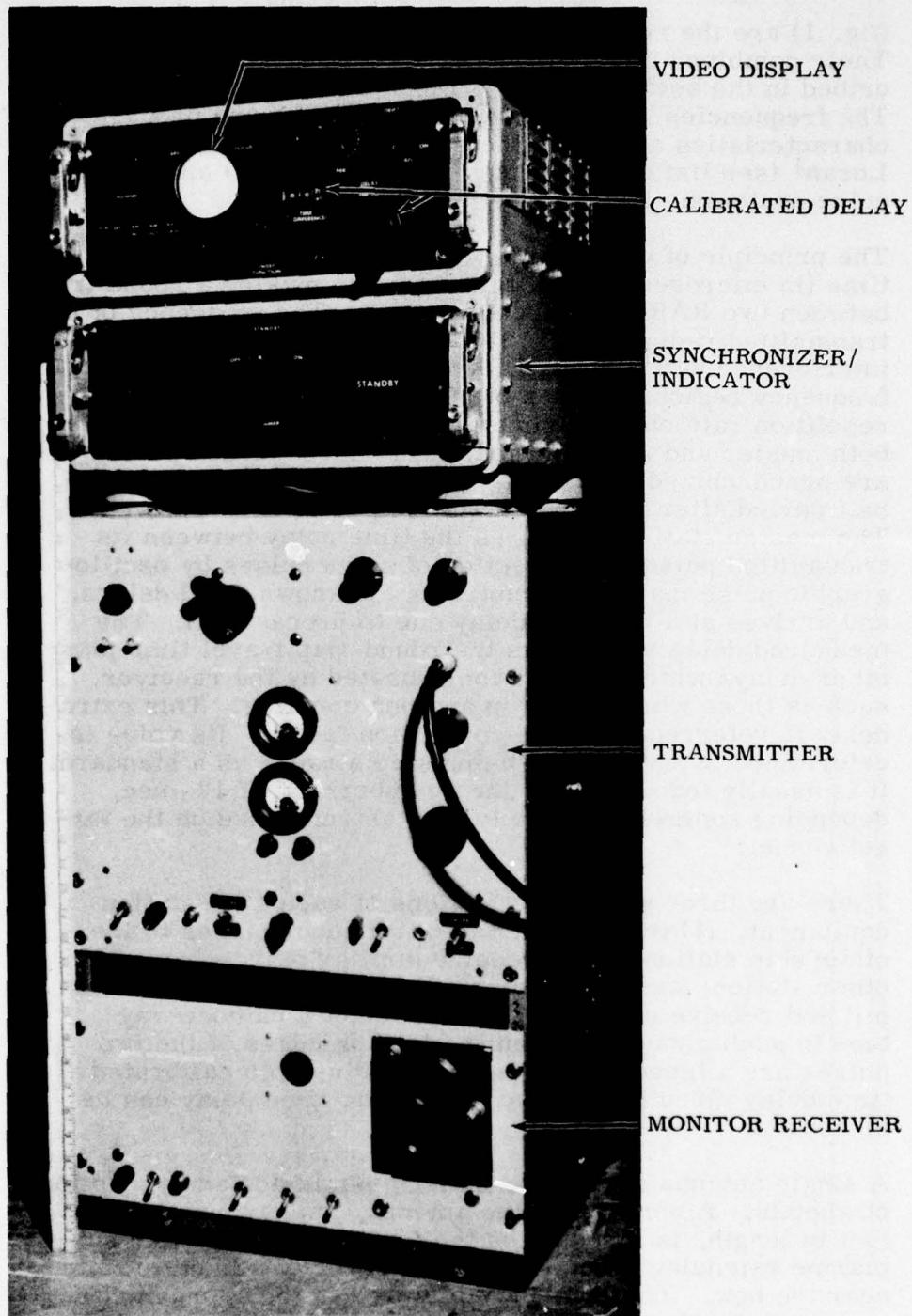


Figure 1. RARIE equipment. A, Master station.

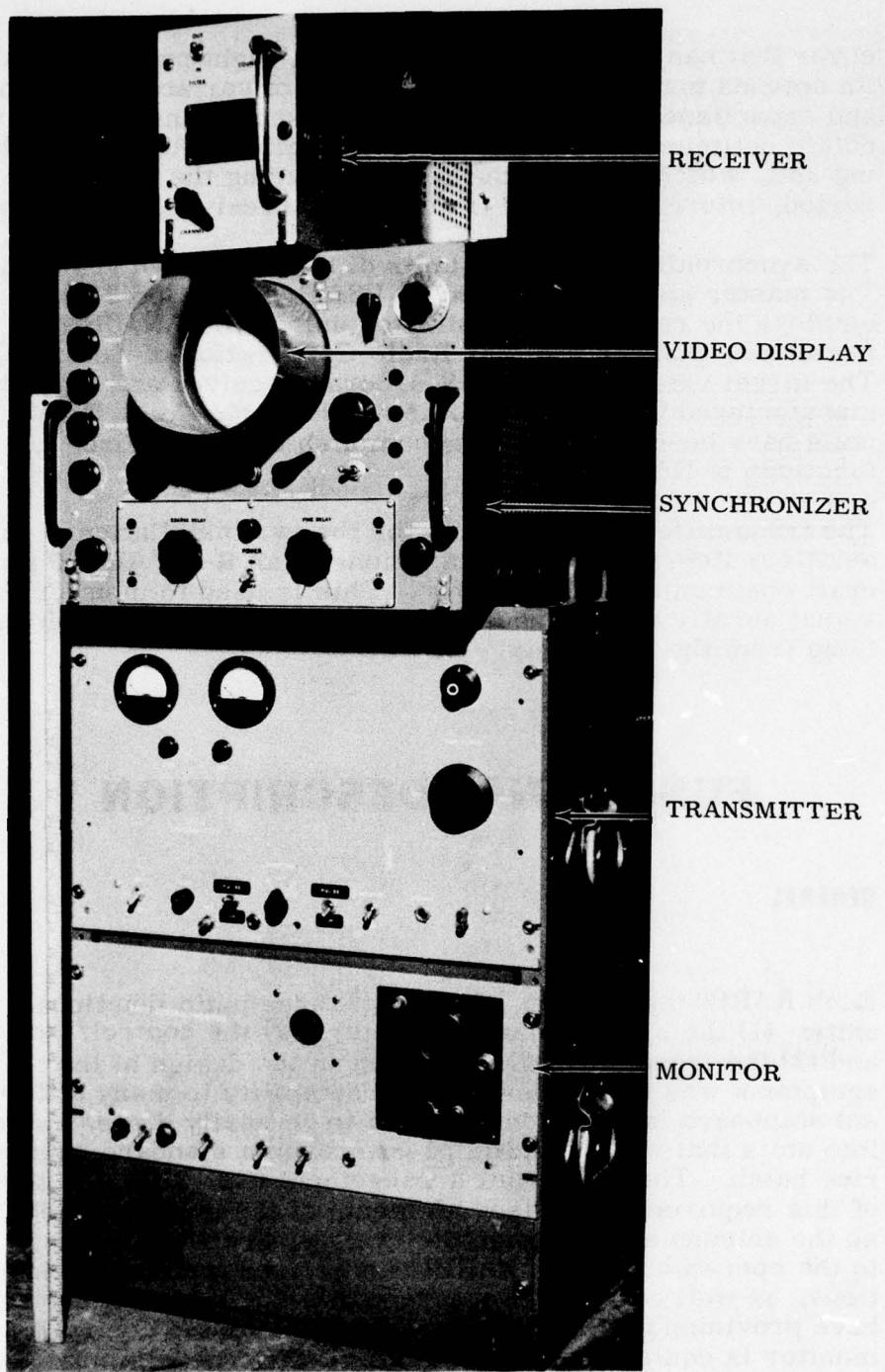


Figure 1. B, Slave station.

cover that has been equipped with water-tight packing glands. An antenna matching circuit consisting of variable inductance and capacitance is provided inside the submarine in order to obtain optimum matching to the transmitter. A T/R switching unit, which protects the receiver during the transmit period, interconnects the transmitter, receiver, and antenna.

The synchronizer/indicator units differ on the two vessels. The master station, installed on USS BAYA (AGSS 318), employs the receiver and indicator unit of the AN/UPN-12 Loran set, manufactured by Radio Corporation of America.³ The target vessel uses a DAS-4 Loran receiver and indicator manufactured by the Fada Radio and Electric Co.⁴ Both units have been modified to accomplish the specialized functions of RARIE.

The transmitters are identical for the two installations. An auxiliary item with both installations is an R-25/ARC-5 aircraft communications receiver. This is used to monitor the signal aurally and for reception of cw and voice communications from the other ship.

FUNCTIONAL DESCRIPTION

GENERAL

Each RARIE installation consists of three main functional units: (1) the synchronizer/indicator, (2) the control/monitor, and (3) the transmitter. A problem in the design of the equipment was the necessity for adaptability to many different shipboard installations. It had to be easily disassembled into units that would readily pass through a standard submarine hatch. The three-unit arrangement (fig. 2) is a result of this requirement. Other elements of the system, such as the antenna and associated circuitry, are equally vital to the operation. Since RARIE can be used for communications, as well as range measurements, the transmitters have provision for amplitude modulation and the control/monitor is equipped with a small aircraft-type communications receiver.

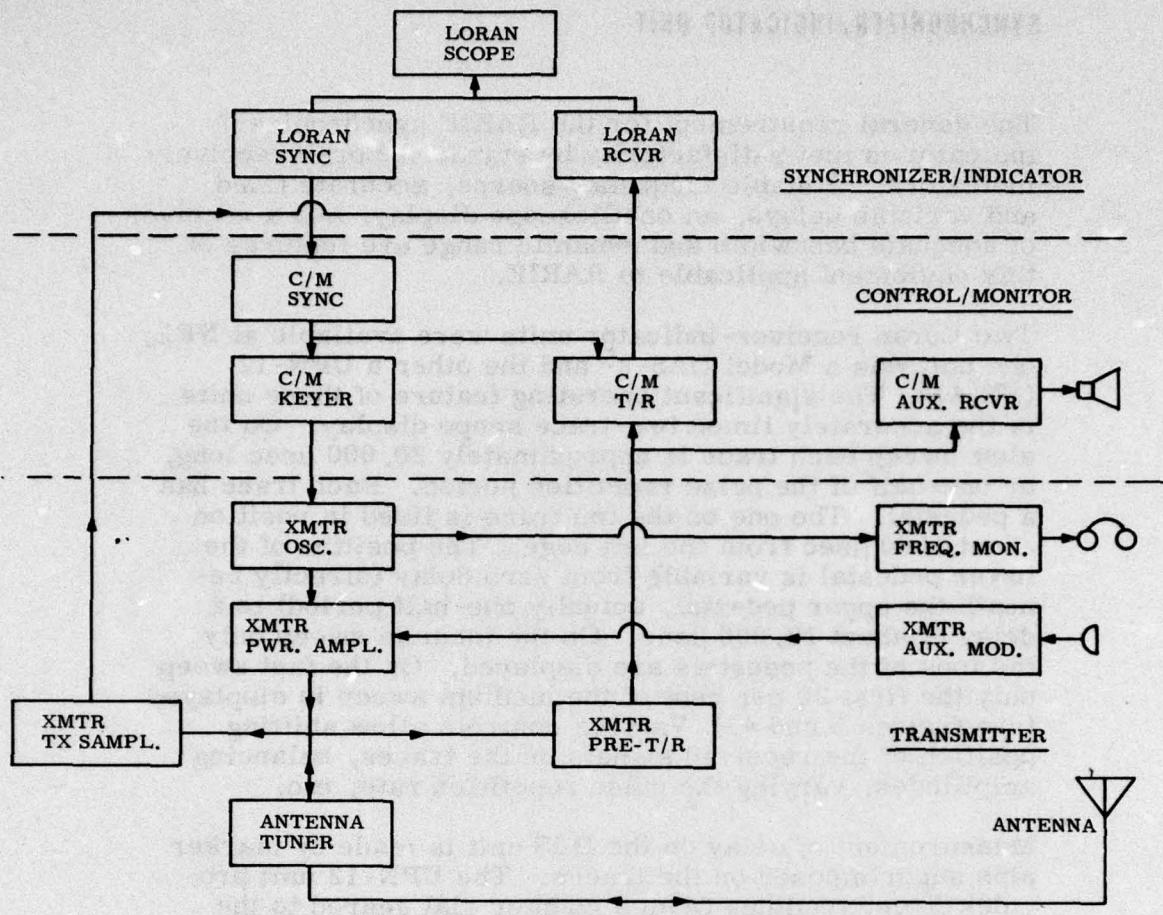


Figure 2. RARIE block diagram.

SYNCHRONIZER/INDICATOR UNIT

The general requirement for the RARIE synchronizer/indicator is met satisfactorily by standard Loran receiver-indicators. A stable frequency source, accurate fixed and variable delays, an oscilloscope display, and a receiver of adequate bandwidth and dynamic range are features of this equipment applicable to RARIE.

Two Loran receiver-indicator units were available at NEL; one unit was a Model DAS-3⁵ and the other a UPN-12 (XN-1).³ The significant operating feature of these units is the accurately timed, two-trace scope display. On the slow sweep each trace is approximately 20,000 μ sec long, or one-half of the pulse repetition period. Each trace has a pedestal. The one on the top trace is fixed in position about 1000 μ sec from the left edge. The position of the lower pedestal is variable from zero delay (directly beneath the upper pedestal, actually one-half period) to a delay of about 12,000 μ sec. On the medium sweep only the tops of the pedestals are displayed. On the fast sweep only the first 20 per cent of the medium sweep is displayed (see figures 3 and 4.) Various controls allow shifting position of the received signals on the traces, balancing amplitudes, varying the pulse repetition rate, etc.

Measurement of delay on the DAS unit is made by marker pips superimposed on the traces. The UPN-12 unit provides direct readings from a counter dial geared to the lower pedestal controls. Therefore, the UPN-12 proved to be best suited for use as the RARIE master synchronizer due to the ease with which delay measurements could be made. Since the slave station is not required to make range measurements, but is only required to provide the necessary delay, the DAS-3 was adapted for use as the RARIE slave.

At the master station the transmitted pulse is keyed at the leading edge of the upper pedestal. The slave station receives the pulse, waits exactly one-half of the pulse repetition period, and sends its reply pulse. At the master station the received pulse is displayed on the lower trace at a separation from the transmit pulse which is directly proportional to the distance between stations. At the slave station the half-period delay is maintained by matching the received pulse from the master station, displayed on the upper trace, with the transmitted slave signal,

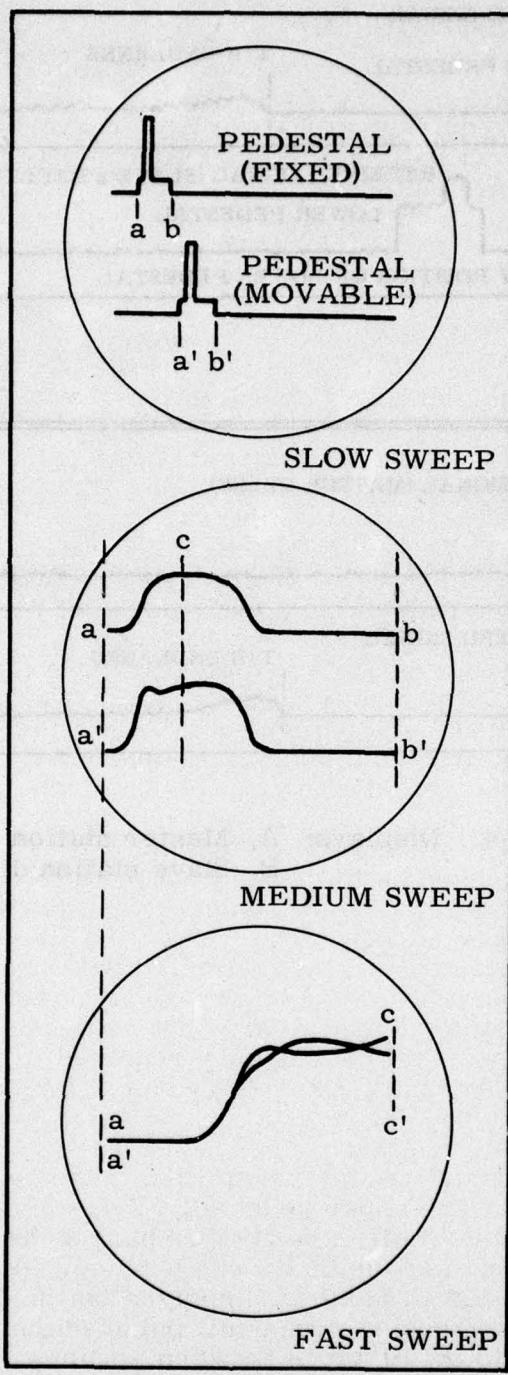


Figure 3. Master station display.

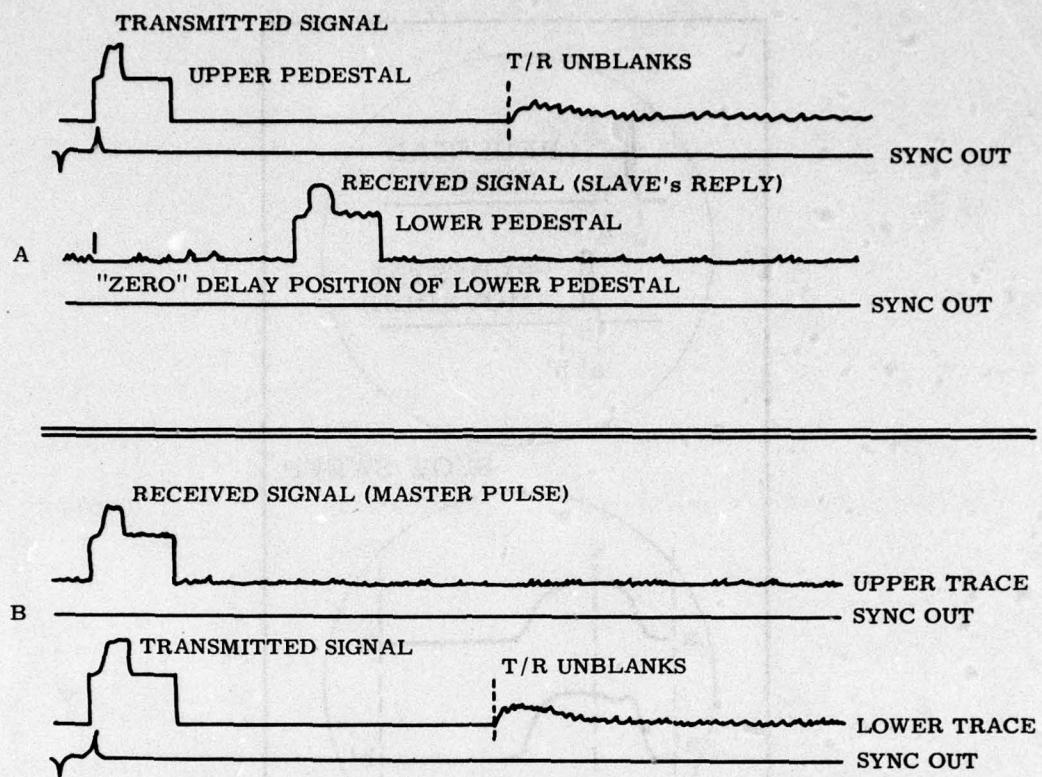


Figure 4. Displays: A, Master station display;
B, Slave station display.

displayed on the lower trace.

The synchronizing signal output provides two functions: (1) it blanks the receiver input by means of a T/R switch, and (2) it keys the transmitter. Logical circuitry in the control/monitor unit provides a short (approximately 50 μ sec) negative-going pulse to initiate T/R switch blanking, and a positive-going pulse to key the transmitter. The T/R pulse is generated, in the UPN-12, at the start of the top trace while the transmit pulse is triggered at the leading edge of the top pedestal. The required sync pulses are both available from the upper pedestal timing circuitry.

Modification of the DAS unit was somewhat more complex. The T/R and transmit pulses are generated on the lower trace. Since the continuously variable lower pedestal position feature is not needed in the slave synchronizer, the fine-delay multivibrator was disconnected. This permits the lower pedestal to be locked in zero delay position. Its position is variable by means of the coarse delay control, but only in large jumps. The fine-delay circuitry now controls the delay, from 0 to 50 μ sec, of the transmit sync pulse relative to the leading edge of the lower pedestal. The same circuitry also provides the negative pulse to blank the receiver by means of the T/R switch. An amplifier and cathode follower were added for pulse shaping and low impedance output to the control monitor unit.

A DAS-4 unit⁴ was recently obtained to replace the older DAS-3. Its circuitry is similar, so the same modifications were made. In addition an AFC circuit was added to synchronize the repetition rate of the slave unit with that of the received signal. This compares the phase of the leading edge of the top pedestal with that of the received signal and generates an error voltage that is applied to a reactance tube in the standard frequency oscillator. It locks in the received signal to one position on the upper pedestal, thus relieving the operator of much manual tuning.

In addition to timing circuit modifications, the receiver section required some adjustment in order to receive the RARIE signals. RARIE operating frequencies were selected to be in comparatively quiet regions of the Loran band (see table 1). The DAS required only adjustment of the tuned circuits. The UPN, however, required new crystals since its conversion oscillator is crystal controlled.

TABLE 1. FREQUENCY ALLOCATION CHART

<u>Frequency (kc/s)</u>	<u>Users</u>
2300	Maritime mobile, mobile, fixed
2000	
2000	Amateur (Western U. S. A.)
1975	
1975	RARIE channel 1 (used locally)
1950	Loran channel 1 (Atlantic, N & W Pacific)
1900	Loran channel 3 (not in use) RARIE channel 3 (used in Arctic)
1850	Loran channel 2 (E, S, & C Pacific)
1825	
1800	Amateur (Eastern U. S. A.)
1750	Loran channel 4 (W Pacific)
1635	
540	Standard broadcast

TRANSMITTER

To provide the required accuracy of range measurement the RARIE transmitter must generate a fast rising, accurately timed pulse at a power level adequate for the desired maximum range. It is necessary, also, that the transmitter be completely silent except when keyed to avoid blocking weak received signals. Loran and EPI do this by using high-power pulsed oscillators. As RARIE includes some continuous transmission operation (AM communications) an oscillator/power amplifier unit was provided. This provides better frequency stability under extreme changes of duty cycle and load.

The transmitter unit consists of two 829B beam tetrodes

in parallel driven by a Colpitts oscillator (fig. 5). The 5881 beam pentode used in the oscillator is keyed by a 6080 dual triode connected between cathode and ground. The plate supply of the oscillator is regulated to prevent frequency instability caused by voltage fluctuations. A 50-volt positive pulse from the control/monitor unit is supplied to the grids of the keyer tube and causes it to conduct and turn on the oscillator. The final amplifier, biased well into the Class C region, has a power gain of approximately 80. The amplifier is matched to the 50-ohm output by a "pi" network. During the pulse operation, 1100 volts is applied to the plates and 550 volts to the screens of the 829B's. This gives a peak input power of approximately 1 kw. Peak output power is 500 watts indicating efficiency of 50 per cent. Since the duty cycle is only 1 per cent, the average dissipation is only 5 watts and is well within the 180-watt capability of the tubes.

For amplitude-modulated operations, such as for voice communications, the power amplifier plate voltage is reduced to 550 volts and the oscillator runs continuously. The screen voltage is controlled by a series gate modulator. This cathode-follower type modulator varies the screen voltage between 100 and 300 volts to provide approximately 75 per cent modulation of the carrier. The peak output power is about 200 watts.

An effort was directed toward developing a crystal-controlled oscillator capable of generating a fast rise pulse. This did not prove practical within the limits of circuit complexity. Instead, a monitor circuit consisting of a crystal oscillator, detector and audio amplifier was added. This compares the frequency of the transmitter oscillator with that of the crystal oscillator. The beat between them is detected, amplified, and monitored on headphones. The operator adjusts frequency of the transmitter until he hears a "zero" beat, indicating no error in transmitted frequency. This procedure requires that the transmitter oscillator run continuously as in AM operation. The frequency stability of the transmitter has been satisfactory, so the monitor has been used only as a convenient check.

CONTROL/MONITOR UNIT

This unit of the RARIE installation is mainly auxiliary equipment associated with the receiver and synchronizer

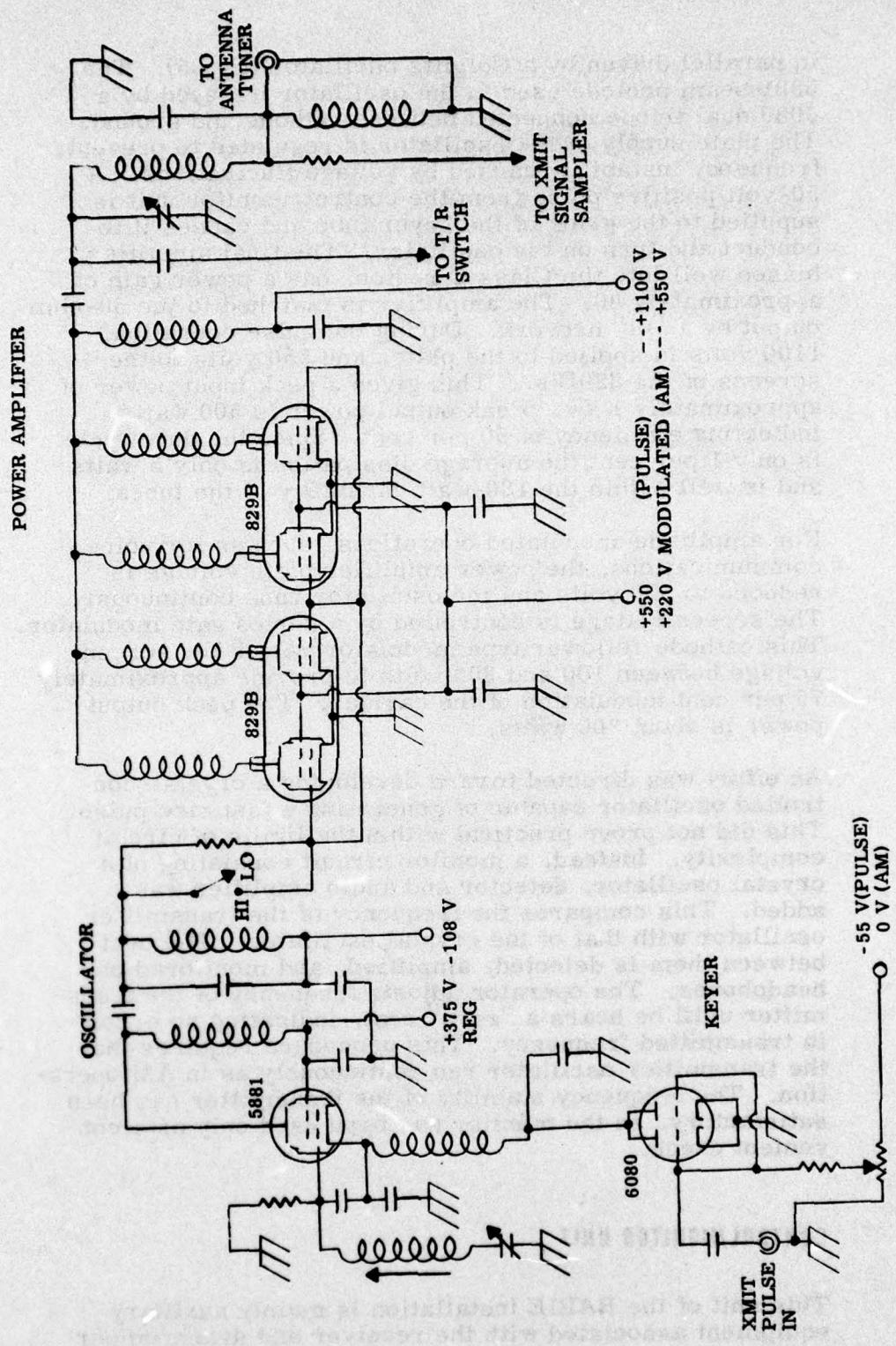


Figure 5. Schematic of transmitter.

circuits. It includes synchronizing logic, T/R switch, communications receiver, and power supply. Discussed here, but actually a part of the transmitter unit, are the pre-T/R switch and the transmitted signal sampler (fig. 6).

The sync logic section generates the driving pulses for keying the transmitter and blanking the T/R switch. These pulses are controlled by the timing signals from the synchronizer/indicator unit. The negative-going timing pulse triggers a one-shot multivibrator which generates a negative 100-volt rectangular pulse, 10,000 μ sec long. This pulse turns the T/R switch to the transmit position to avoid overloading the receiver by the transmitted signal. The other timing pulse (positive-going) triggers another one-shot multivibrator generating a 200- μ sec rectangular pulse which goes to the keyer tube in the transmitter.

The relative amplitudes of the received and transmitted signals may differ by a factor of 10^5 , which is much greater than the dynamic range of the Loran receivers. The T/R switch prevents overloading of the receiver by the transmitted signal, but permits a suitably attenuated sample of the transmitted signal to pass through to the receiver, so that an accurate match of the pulses can be made. The T/R system consists of a three-stage, broadband amplifier. The first stage saturates during transmission, but the following two stages are biased off by the pulse from the T/R multivibrator which blanks the receiver. All stages are well shielded, providing a total attenuation of more than 100 db when blanked off. A small amount of the transmitted signal is needed, so a resistive voltage divider bypasses the T/R section, providing an undistorted sample of the transmission.

The communications receiver is a surplus ARC-5/R-25, 1.5 - 3.0 Mc/s aircraft type receiver. The audio and power supply sections have been modified somewhat for the present application. It has proved quite adequate for use with RARIE.

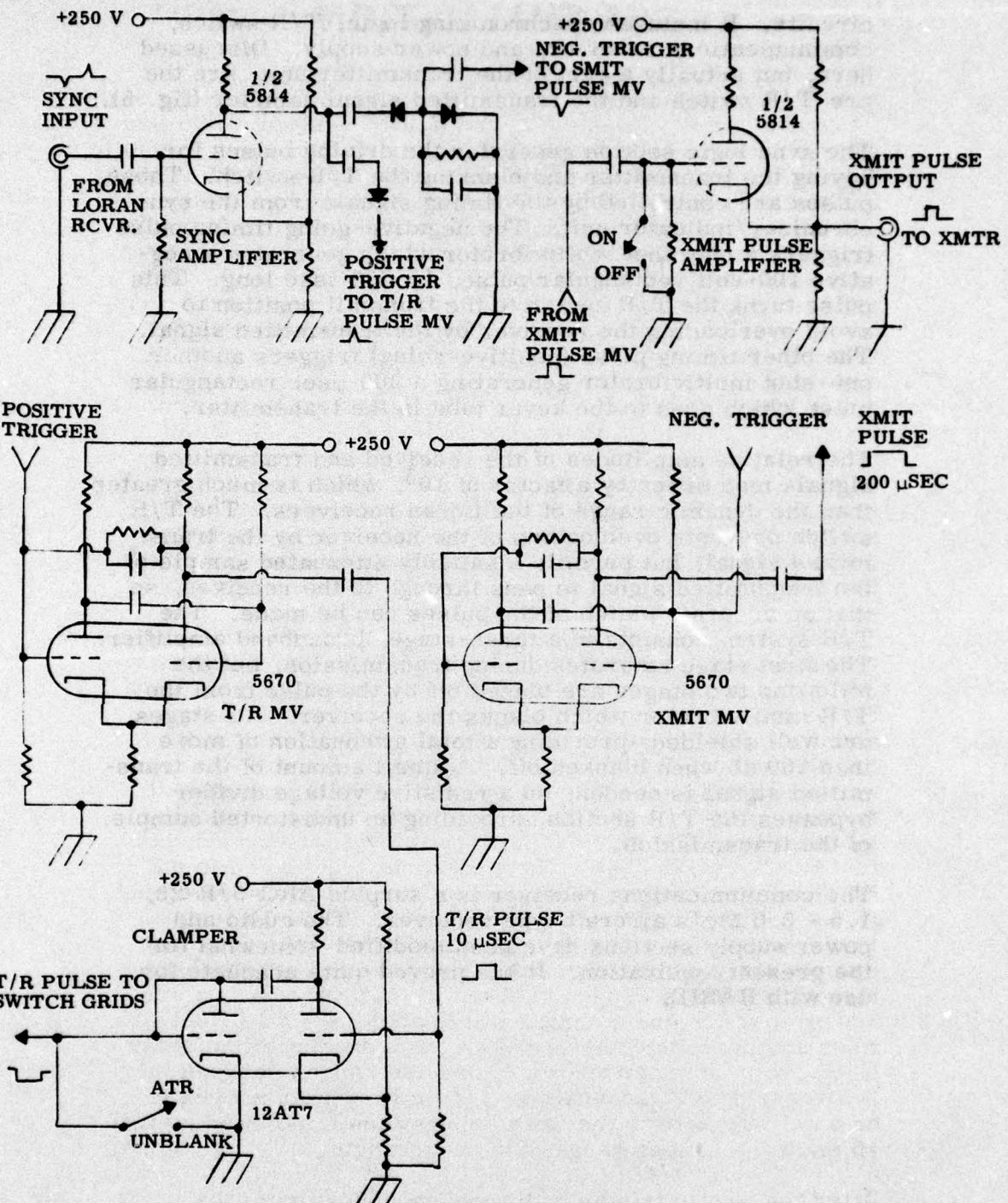


Figure 6. Schematic of sync circuits.

SEA EVALUATION

During the development of the RARIE system, field tests were conducted at sea about 100 miles west of Point Arguello. The first significant test was conducted during the period 21-31 March 1960. During the tests an opportunity to evaluate the system with Lorac⁶ presented itself. The master station was installed aboard USS BAYA and the other station was placed aboard USS MARYSVILLE (EPCER 857). The primary mission of the trip was precision range and bearing tests using the Lorac system. The RARIE portion of the test was conducted on a not-to-interfere basis.

While ranges obtained with the RARIE system compared favorably with those obtained with Lorac, the important fact learned from this test was that the use of flexible, high Q , whip antennas caused too much variation in range readings due to changes in tuning (and hence delay) as the antennas swayed in the wind. From these tests came the decision to use horizontal line antennas for each installation.

The system really proved itself during an Arctic trip conducted during the summer of 1960. For the BAYA's installation a line antenna was rigged from the periscope shears to the anchor light mast on the bow. The lead-in from the antenna came through the forward torpedo loading hatch to the equipment located in the Lorad room in the BAYA. It was possible to have the antenna tuning coils located with the equipment rather than on deck as in the previous installation. The slave station equipment was installed on USS ROCK (AGSS 274). The equipment was placed in the ROCK's after battery compartment where it was convenient to use the ship's after line antenna for the RARIE installation. Except for a few minor breakdowns, the equipment on both ships operated reliably and provided dependable measurements of ranges between the two vessels. It was found that the line antennas eliminated the signal fluctuations and permitted the use of a constant correction factor of 12 μ sec. It was possible to provide ranges between the two vessels to an accuracy of 1/10 mile. This proved to be a definite help to the Lorad operations in positioning the ships at the proper ranges for echo-ranging.

After the Arctic trip an additional modification to the RARIE equipment was incorporated. A modulator was

added to each transmitter so that voice communications between stations would also be available. This turned out to be more satisfactory for communicating between the scientific parties aboard the two ships than relying on cw.

During the four weeks of Lorad tests in March of 1961, RARIE was used exclusively for initial positioning of the target ship. The slave station was placed aboard three different ships during this period. The first week, it was used aboard USS REXBURG (EPCER 855); the second week on USS VOLADOR (SS 490); the third week back on the REXBURG; and during the final week, aboard USS RON-QUIL (SS 396). RARIE was used to position the target ships at the desired ranges on all tests. The ranges agreed with the sonar ranges obtained from station-keeping and other navigational aids.

CONCLUSIONS

RARIE is a practical and useful system for measuring the relative range between two vessels located beyond the range of their radars. During the Lorad tests conducted in 1960 and spring of 1961, an estimated 30 per cent increase in operating time for obtaining useful Lorad data was achieved by using RARIE to provide positive positioning of the ships at the start of each event.

RECOMMENDATIONS

RARIE equipment should be used as standard station-keeping equipment during all tests which require two ships operating together to be stationed accurately at ranges greater than the capabilities of their respective radars.

It is further recommended that RARIE be redesigned with simplification and miniaturization of components as the primary objective.

APPENDIX: OPERATING PROCEDURE

MASTER STATION

Turn on: Power switch for transmitter, T/R unit, and UPN-12 unit to standby. After allowing sufficient time for units to warm up, turn the transmitter to either "Hi" or "Lo" power and the UPN-12 to "Operate." The Sweep Function switch should be in the No. 1 position. The Pulse switch, located on the transmitter unit, may now be turned to the "On" position. The transmitted pulse will appear along the forward edge of the upper pedestal of the CRT display. The pulse received from the other vessel will appear on the lower trace of the display. Adjust the inner and outer knobs of the "Bal-Gain" control so that the amplitudes of the two signal spikes are about equal. Turn the delay crank to add or subtract delay until the received signal is located on the lower pedestal. The sweep function switch is then turned to the No. 2 position. A finer adjustment of the two traces may now be made so that the received pulse is directly below the transmitted pulse. Now the Sweep Function switch may be turned to the No. 3 position. One of the two pulses will now be superimposed upon the other. The Fine Delay control is now adjusted so that the leading edges of the two signals are aligned. The calibrated dial located to the left of the delay control may now be read. The reading represents, to the nearest microsecond, the round-trip radio frequency travel time plus the uncompensated calibration error. This reading must be modified by subtracting the correction factor, a constant which represents the sum of the delays encountered in the system. In order to obtain the range in miles, the modified figure is divided by 12.36, the time required for a radio signal to travel one nautical mile and return. The result is the range between the two vessels.

SLAVE STATION

The method of operation for the slave station is very similar to that for the master station except that with the DAS-4 Loran receiver and indicator, different dials are involved. Since the time delay dials are not suitably calibrated, the operator is not able to make direct range

readings at the slave station. His function is to maintain alignment of the leading edges of the transmitted and received pulses on the CRT display. This is done by adjusting the "Fine Delay" knob with "Sweep Speed" switch on "Fast" and the "Fast Sweep" switch at the No. 1 position. It is extremely important that this alignment of the traces be carefully done as accurate range readings can be made on the other vessel only when the leading edges of the traces are accurately matched.

Further information on the operation and adjustments of either the UPN-12 or the DAS-4 may be found in the instruction manuals published by the manufacturers of these equipments.

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1. Radio ranging systems
2. RARIE

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III. Wheeler, R. B.

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Commander Key West Test & Evaluation Det.

Air Development Squadron ONE (VX-1)

Fleet Sonar School

Fleet ASW School, San Diego

Beach Jumper Unit ONE

Beach Jumper Unit TWO

Naval Air Development Center, Library

Naval Missile Center, Technical

Library, Code 5320

Naval Air Test Center (NANEP)

Naval Ordnance Laboratory, Library (2)

Naval Ordnance Test Station, Pasadena

Annex Library

Naval Ordnance Test Station, China Lake

Code 753 Technical Director

David Taylor Model Basin, Library

Naval Engineering Experiment Station

Library

Navy Mine Defense Laboratory, Code 712

Naval Training Device Center

Naval Underwater Ordnance Station

Office of Naval Research, Pasadena

Naval Medical Research Laboratory

Naval Personnel Research Field Activity, Washington, D. C.

Navy Hydrographic Office, Library

Oceanography Division

Navy Underwater Sound Laboratory

Code 1450 (3)
 Harold Nash Stanley Peterson
 (Secret) (1)

Lant Fleet, ASW Tactical School

Naval Research Laboratory

Code 2027 (2) Code 4000
 Code 5400 Code 5120

Navy Underwater Sound Reference Laboratory, Library

Naval Postgraduate School
 (Library) (2)

Navy Representative, Project LINCOLN,
 MIT

Asst. SECNAV, Research & Development Department of Defense, Director of Def.
 Res. & Engr. (Tech. Library)
 (Weapons Systems Evaluation Group)
 (Guided Missiles)

Asst. Chief of Staff, G-2, US Army
 (Document Library Branch) (3)

Army Electronic Proving Ground
 (Technical Library)

Redstone Arsenal (Technical Library)

Beach Erosion Board, US Army

Air Defense Command (Office of Operations Analysis)

Air University Library, AUL3T-5028

Air Force Cambridge Research Center
 CRQSL-1

Rome Air Development Center (RCRES-4C)

Holloman Air Force Base (SRTEL)

University of California, Marine Physical Laboratory

University of California, Scripps Institution of Oceanography

National Research Council (Committee on Undersea Warfare, Executive Sec.) (2)

Brown University, Research Analysis Group

Pennsylvania State University, Ordnance Research Laboratory

The University of Texas

Military Physics Laboratory

Defense Research Laboratory

University of Washington, Applied Physics Laboratory

Woods Hole Oceanographic Institution

Bell Telephone Laboratories, Murray Hill

Bendix Aviation Corp., North Hollywood

Edo Corp., Long Island

General Electric Co., Syracuse

Raytheon Mfg. Co., Wayland

Sangamo Electric Co., Springfield

Laboratory of Marine Physics, New Haven
 Columbia University, Hudson Laboratories

Harvard University, Acoustics Research Laboratory, Dr. F. V. Hunt

University of Michigan Research Institute